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September 22, 2000

Asst. Commissioner of Patents
Washington, D.C. 20231

PATENT APPLICATION TRANSMITTAL LETTER

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DISTANCE CORRECTING APPARATUS OF SURROUNDINGS
MONITORING SYSTEM AND VANISHING POINT CORRECTING
APPARATUS THEREOF

Attorney Docket No.: 32405W056

Sir:

Transmitted herewith for filing are the following:

New patent application including 51 pages of text, 14 sheets of formal drawings,
unsigned Declaration, Claim For Foreign Priority with attached certified copy of
foreign priority document and no fees.

Respectfully submitted,
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09/22/00
J0772 U.S. PTO

J0615 U.S. PTO
09/22/00
09/22/00

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1 TITLE OF THE INVENTION

2 DISTANCE CORRECTING APPARATUS OF SURROUNDINGS MONITORING SYSTEM
3 AND VANISHING POINT CORRECTING APPARATUS THEREOF.

4

5 BACKGROUND OF THE INVENTION

6 1. Field of the invention

7 The present invention relates to a distance correcting
8 apparatus of a surroundings monitoring system for correcting
9 distance information containing errors caused by a positional
10 deviation of a stereoscopic camera and to a vanishing point
11 correcting apparatus of the system.

12 2. Discussion of the background art

13 In recent years, a stereoscopic surrounding
14 monitoring apparatus using a pair of left and right cameras, that
15 is, a stereoscopic camera, having solid image element like CCD
16 mounted on a vehicle and the like has been watched by concerned
17 engineers. To detect a distance to an object, first respective
18 pixel blocks having coincidence of brightness are found in left
19 and right images (stereo matching), then distance data are
20 calculated according to the principle of triangulation from a
21 parallax, namely a relative deviation amount, between both pixel
22 blocks. Consequently, in order to calculate distance data with
23 high reliability, it is desirable that there exists no positional
24 deviation other than the parallax in a pair of left and right
25 images (stereo images). In actual world, however, the

1 stereoscopic camera has some amount of positional errors such
2 as horizontal or vertical deviations (parallel deviations), a
3 rotational deviation and the like, caused when the camera is
4 installed on a vehicle and the like. Particularly, the horizontal
5 deviation directly produces an error in an parallax and as a result
6 the distance calculated based on the parallax differs from a real
7 one.

8 With respect to this, Japanese Patent Application
9 Laid-open No. Toku-Kai-Hei 10-307352 discloses a technology in
10 which the positional deviation of the stereoscopic camera is
11 corrected by applying a geometric transformation to the
12 stereoscopic image. That is, when an initial adjustment of the
13 positional deviation is made or when a readustment of the
14 positional deviation generated by aged deterioration is made,
15 a dedicated correction detecting device is connected with an image
16 correction apparatus performing the affine transformation to
17 calculate the difference of angle of view, a rotational deviation
18 or a parallel deviation of the stereoscopic image obtained by
19 imaging a specified pattern for adjustment and to establish
20 (reestablish) parameters of the affine transformation according
21 to the result of the calculation. The positional deviation is
22 equivalently corrected by applying the affine transformation
23 to images based on thus established affine parameters.

24 However, according to the aforesaid prior art, a
25 special adjustment pattern is imaged by the stereoscopic camera

1 and the deviation is corrected based on the position of the pattern
2 in images. Accordingly, when the correction is performed, it is
3 necessary to interrupt the ordinary surroundings monitoring
4 control and as a result this prior art is not suitable for a real
5 time processing in which the monitoring control is carried out
6 concurrently.

7

8 SUMMARY OF THE INVENTION

9 It is an object of the present invention to provided
10 a surroundings monitoring apparatus capable of correcting a
11 parallax including errors, in particular, an error caused by
12 horizontal deviation, in parallel with a surroundings monitoring
13 control. It is further object of the present invention to provide
14 a surroundings monitoring apparatus in which the accuracy of
15 measuring distance is raised by using the corrected parallax.
16 It is another object of the present invention to provide a
17 surroundings monitoring apparatus in which, when three-
18 dimensional information of an object is obtained using a vanishing
19 point established beforehand, the accuracy of three-dimensional
20 information of the object is raised by correcting this vanishing
21 point.

22 To achieve these objects, a distance correcting
23 apparatus of a surroundings monitoring system, comprises a stereo
24 imaging means for stereoscopically taking a pair of images, a
25 parallax calculating means for calculating a parallax based on

1 the pair of images, a distance calculating means for calculating
2 a distance to an object based on the parallax and a parameter
3 for correcting the distance, an approximation line calculating
4 means for calculating a plurality of approximation lines
5 extending in the distance direction in parallel with each other
6 based on the images, a vanishing point calculating means for
7 calculating a vanishing point of the images from a point of
8 intersection of the approximation lines and a parameter
9 correcting means for correcting the parameter based on the
10 vanishing point.

11

12 BRIEF DESCRIPTION OF THE DRAWINGS

13 Fig. 1 is a block diagram showing a construction of
14 a stereoscopic type vehicle surroundings monitoring apparatus
15 according to a first embodiment of the present invention;

16 Fig. 2 is a flowchart showing steps for correcting a
17 parallax according to a first embodiment;

18 Fig. 3 is a flowchart continued from Fig. 2;

19 Fig. 4 is a flowchart showing steps for updating a
20 parallax correction value DP according to a first embodiment;

21 Fig. 5 is a flowchart showing steps for updating a
22 parallax correction value DP according to a second embodiment;

23 Fig. 6 is a block diagram showing a construction of
24 a stereoscopic type vehicle surroundings monitoring apparatus
25 according to a third embodiment of the present invention;

1 Fig. 7 is a flowchart showing steps for updating a
2 parallax correction value SHFT1;

3 Fig. 8 is a diagram for explaining a calculated road
4 height;

5 Fig. 9 is a diagram showing a relationship between a
6 calculated road height and an actual road height;

7 Fig. 10 is a diagram for explaining a deviation caused
8 by the difference between an actual road height and a calculated
9 road height;

10 Fig. 11 is a diagram showing an example of a lane marker
11 model;

12 Fig. 12 is a diagram for explaining lane marker edges
13 of a reference image;

14 Fig. 13 is a diagram for explaining a calculation method
15 of a vanishing point in a reference image;

16 Fig. 14 is a block diagram showing a construction of
17 a stereoscopic type vehicle surroundings monitoring apparatus
18 according to a fourth embodiment of the present invention;

19 Fig. 15 is a flowchart showing steps continued from
20 Fig. 2 according to a fourth embodiment;

21 Fig. 16 is a diagram showing an example of an image
22 of an indoor robot; and

23 Fig. 17 is a diagram showing an example of an image
24 of a scenery in front of a railway rolling stock.

25

1 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

2 Fig. 1 is a block diagram of a stereoscopic type
3 surroundings monitoring apparatus using an adjusting apparatus
4 concerned with the embodiment. A stereoscopic camera for imaging
5 a surrounding scenery of a vehicle is composed of a pair of
6 cameras 1, 2 incorporating an image sensor such as CCD and the
7 like and mounted in the vicinity of a room mirror of the vehicle.
8 The cameras 1, 2 are mounted at a specified interval in the
9 transversal direction of the vehicle. A main camera 1 is for
10 obtaining a reference image data and is mounted on the right side
11 when viewed in the traveling direction of the vehicle. On the
12 other hand, a sub camera 2 is for obtaining a comparison image
13 data and is mounted on the left side when viewed in the traveling
14 direction of the vehicle. In a state of the cameras 1, 2
15 synchronized with each other, analogue images outputted from the
16 respective cameras 1, 2 are adjusted in an analogue interface
17 3 so as to coincide with an input range of circuits at the latter
18 stage. Further, the brightness balance of the images is adjusted
19 in a gain control amplifier (GCA) 3a of the analogue interface
20 3.

21 The analogue image signals adjusted in the analogue
22 interface 3 are converted into digital images having a specified
23 number of brightness graduations (for example, a grayscale of
24 256 graduations) by an A/D converter 4. Respective data
25 digitalized are subjected to an affine transformation in a

1 correction circuit 5. That is, the positional error of the
 2 stereoscopic cameras 1, 2 which is caused when the cameras 1,
 3 2 are installed, generates deviations in stereoscopic images such
 4 as a rotational deviation, parallel deviation and the like. The
 5 error is equivalently corrected by applying the affine
 6 transformation to the images. In this specification, a term
 7 "affine transformation" is used for comprehensively naming a
 8 geometrical coordinate transformation including rotation,
 9 movement, enlargement and reduction of images. The correction
 10 circuit 5 applies a linear transformation expressed in Formula
 11 1 to original images using four affine parameters θ , K , SHFTI
 12 and SHFTJ.

13 [Formula 1]

$$\begin{pmatrix} i' \\ j' \end{pmatrix} = K \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} i \\ j \end{pmatrix} + \begin{pmatrix} \text{SHFTI} \\ \text{SHFTJ} \end{pmatrix}$$

14
 15
 16
 17 where (i, j) is coordinates of an original image and (i', j')
 18 is coordinates after transformation. Further, affine parameters
 19 SHFTI, SHFTJ mean a transference in a "i" direction (horizontal
 20 direction of image), a transference in a "j" direction (vertical
 21 direction of image), respectively. Further, affine parameters
 22 θ , K indicate a rotation by θ , an enlargement (reduction in case
 23 of $|K| < 1$) by K times, respectively. The affine transformation
 24 applied to the stereoscopic image assures a coincidence of the
 25 horizontal line in both images, which is essential for securing

1 the accuracy of the stereo matching. The hardware constitution
2 of the correction circuit 5 is described in Japanese Patent
3 Application Laid-open No. Toku-Kai-Hei 10-307352. If necessary,
4 the reference should be made to the disclosure.

5 Thus, through such image processing, the reference
6 image data composed of 512 pixels horizontally and 200 pixels
7 vertically are formed from output signals of the main camera 1.
8 Further, the comparison image data having the same vertical length
9 as the reference image and a larger horizontal length than the
10 reference image, for example composed of 640 pixels horizontally
11 and 200 pixels vertically, are formed from output signals of the
12 sub camera 2. The coordinate system i - j of image on a two-
13 dimensional plane has an origin at the left below corner of the
14 image, an i coordinate in the horizontal direction and a j
15 coordinate in the vertical direction. One unit of the coordinate
16 system is one pixel. These reference image data and comparison
17 image data are stored in an image data memory 7.

18 A stereo calculating circuit 6 calculates a parallax
19 d based on the reference image data and the comparison image data.
20 Since one parallax d is produced from one pixel block constituted
21 by 4×4 pixels, 128×50 parallax data are calculated per one
22 reference image of a frame size. In calculating a parallax d_i
23 of a given pixel block in a reference image, first a corresponding
24 pixel block of a comparison image is identified by searching an
25 area having the same brightness as that given pixel block of the

1 reference image. As well known, the distance from the camera to
2 an object projected in a stereo image is expressed as a parallax
3 in the stereo image, namely a horizontal deviation amount between
4 the reference and comparison images. Accordingly, in searching
5 the comparison image, the search is performed on the same
6 horizontal line (epipolar line) as a j coordinate of the reference
7 image. In the stereo calculating circuit 6, the correlation is
8 evaluated for every pixel block between the object pixel block
9 and the searching pixel block while shifting a pixel one by one
10 on the epipolar line (stereo matching).

11 The correlation between two pixel blocks can be
12 evaluated for example using a city block distance which is one
13 of well known evaluation methods. The stereo calculating circuit
14 6 obtains a city block distance for every area (having the same
15 area size as the object pixel block) existing on an epi-polar
16 line and identifies an area whose city block distance is minimum
17 as a correlation object of the object pixel block. The deviation
18 amount between the object pixel block and the identified
19 correlation object equals to a parallax d_i . The hardware
20 constitution for calculating the city block distance and the
21 method of determining the correlation object is disclosed in
22 Japanese Patent Application No. Toku-Kai-Hei 5-114009. If
23 necessary, the reference should be made to the disclosure. The
24 parallax d calculated by the stereo calculating circuit 6 is
25 stored in the distance data memory 8.

1 The micro-computer 9 or when seeing it from a functional
2 point of view, a recognition section 10 which is a functional
3 block, read image data of a reference image out from an image
4 data memory 7 and recognizes an object (for example, a preceding
5 vehicle and the like) projected in the reference image using a
6 known image recognition technique. Further, the recognition
7 section 10 calculates a distance Z to the object according to
8 the following formula parameterizing a parallax d read out from
9 the distance data memory 8.

10 [Formula 2]

$$11 \quad Z = KZH / (d - DP)$$

12 where KZH is a constant (base line length of camera / horizontal
13 angle of view) and DP is a vanishing point parallax. In this
14 embodiment, the vanishing point parallax DP is a parallax
15 correction value (variable) which is calculated in a correction
16 calculating section 13.

17 Further, the recognition section 10 performs a
18 recognition of road configurations. Road configurations, that
19 is, left and right lane markers (passing line, no passing line
20 and the like) are expressed in a three-dimensional space as
21 functions having parameters established so as to coincide with
22 actual road configurations such as straight roads, curved roads
23 or up-and-down roads. In this embodiment, a term "lane marker"
24 represents a continuous white line-like marker drawn on a road,
25 although the present invention is not limited to such lane markers.

1 The method of calculating a lane marker model according to this
2 embodiment will be described by reference to Fig. 12.

3 First, a white line edge Pedge, namely, a portion
4 showing a large variation in brightness, is identified. The white
5 line edge Pedge is searched separately for the left side and right
6 side of a lane, respectively. A plurality of left white line edges
7 Pedge1 and a plurality of right white line edges Pedge2 are
8 identified respectively. Specifically, the brightness edges
9 satisfying following three conditions are recognized as white
10 line edges Pedge.

11 (Conditions of white line edge)

12 1. Brightness variation is larger than a specified value
13 and pixels on the outer side (edge side of image) have a larger
14 brightness than those on the inner side (central side of image).

15 The white line edges Pedge caused by the left and right
16 lane markers are brightness edges at the boarder of lane marker
17 and paved surface, as shown in Fig. 12.

18 2. With respect to candidates of the white line edge Pedge
19 satisfying the condition 1, another edge exists outside of one
20 edge on the same horizontal line as the candidates and brightness
21 of pixels on the inner side is larger than that of pixels on the
22 outer side.

23 Since the lane marker has a specified width, there is
24 another boarder on the outer side of the white line edge Pedge.
25 This condition is provided in view of the feature of lane marker.

1 3. With respect to pixel blocks including the white line
 2 edge Pedge satisfying the condition 1, a parallax d has been
 3 calculated.

4 If there is no parallax d where a white line edge exists,
 5 the white line edge Pedge is not effective for recognizing a road
 6 configuration.

7 The recognition section 10 calculates coordinates (X,
 8 Y, Z) in real space by substituting coordinates (i, j) and its
 9 parallax d for every identified white line edge Pedge into the
 10 following Formula 3 and Formula 4.

11 [Formula 3]

$$12 \quad Y = CAH - Z(JV - j)PWV$$

14 [Formula 4]

$$15 \quad X = r/2 + Z(IV - i)PWH$$

16 where CAH is an installation height of cameras 1, 2; r is an
 17 interval between cameras 1, 2; PWV and PWH are a vertical and
 18 horizontal angle of view per one pixel, respectively; IV and JV
 19 are an i coordinate and j coordinate of a vanishing point V
 20 established, respectively.

21 Further, the coordinate system in real space comprises
 22 an origin placed on the road surface immediately beneath of the
 23 center of the cameras 1, 2, X axis extending in the widthwise
 24 direction of the vehicle, Y axis extending in the vertical
 25 direction of the vehicle and Z axis extending in the longitudinal

1 direction of the vehicle. When the coordinates (i, j) and the
2 parallax d of an object (a preceding vehicle, a solid object,
3 a road and the like) projected on the image are identified, the
4 coordinates (X, Y, Z) of the object in real space can be
5 unconditionally identified according to the transformation
6 formulas shown in Formulas 2 through 4.

7 A lane marker model is identified based on the
8 coordinates (X, Y, Z) of thus identified respective white line
9 edges Pedge in real space. The lane marker model is prepared in
10 such a manner that approximation lines are obtained for every
11 specified interval with respect to each of the left and right
12 white line edges Pedge1, Pedge2 within a recognition range (for
13 example, a range of 84 meters away in front of the vehicle from
14 camera) and thus obtained approximation lines are combined like
15 broken lines. Fig. 11 shows an example of a lane marker model
16 in which the recognition range is divided into seven segments
17 and the left and right white line edges Pedge1, Pedge2 for each
18 segment are approximated to a linear equation expressed as follows
19 according to the least square method.

20 [Formula 5]

21 (Left lane marker model L)

22
$$X = a_L \cdot Z + b_L$$

23
$$Y = c_L \cdot Z + d_L$$

24 (Right lane marker model R)

25
$$X = a_R \cdot Z + b_R$$

$$Y = C_R \cdot Z + d_R$$

These lane marker models L, R are constituted by a curve function ($X = f(Z)$) for expressing a curvature of road and a gradient function ($Y = f(Z)$) for expressing a gradient or condition of unevenness of road. Accordingly, the three-dimensional feature of the road in real space can be expressed by the left and right lane marker models L, R. Respective white line edges and left and right lane marker models L, R calculated in the recognition section 10 are transmitted to a correction calculating section 13.

The recognition section 10 actuates a warning device 11 such as a display monitor or a speaker when it is judged that a warning is needed based on the result of recognition of preceding vehicles or road configurations. Further, the recognition section 10 controls a control device 12 to carry out miscellaneous vehicle controls such as engine output control, shift control of automatic transmission, brake control and the like.

Next, the method of correcting distance information according to the embodiment will be briefly described by reference to Fig. 8.

Assuming that the Z axis of the vehicle is always horizontal with respect to an even road without up-and-down, that is, there is no pitching of the vehicle, the height Y of the road surface is expressed by a line L_r with a gradient a ($a=0$). This line L_r is called an actual road surface height. Letting

1 coordinates of a point p_1 (hereinafter referred to as a road
 2 surface point) projected on the reference image be (i_1, j_1) and
 3 letting its parallax be d_1 , the position of this road surface
 4 point p_1 in real space is identified unconditionally as
 5 coordinates (x_1, y_1, z_1) .

6 [Formula 6]

$$7 \quad z_1 = KZH / (d_1 - DP)$$

8

9 [Formula 7]

$$10 \quad y_1 = CAH - z_1 (JV - j_1) PWH$$

11

12 [Formula 8]

$$13 \quad x_1 = r/2 + z_1 (IV - i_1) PWH$$

14

15 In case where a flat road without up-and-down horizontally exists,
 16 if the distance z_1 calculated from the parallax d_1 includes no
 17 error, the height y_1 calculated from Formula 7 should be 0. That
 18 is, if the value of the distance z_1 is identical to an actually
 19 measured value, a line Lr' (hereinafter, referred to as a
 20 calculated road surface height) connecting an origin and the road
 21 surface point p_1 agrees with the actual road surface height.
 22 Namely, the gradient of the calculated road surface height Lr'
 23 becomes 0. On the other hand, in case where the value of the
 24 distance z_1 contains errors and differs from the actually measure
 25 value, the height y_1 calculated from Formula 7 is not equal to

1 0, the calculated road height Lr' having a specified gradient
 2 a' ($a' = y1/z1 \neq 0$).

3 The reason why the calculated height $y1$ is not equal
 4 to 0 is that the parallax $d1$ containing errors due to the effect
 5 of the horizontal deviation of the stereoscopic camera is
 6 calculated and these errors are not properly offset by the
 7 vanishing point parallax DP (corresponding to a parallax
 8 correction value). Hence, if a deviation amount of the gradient
 9 a' ($a' \neq 0$) of the calculated road surface height Lr' with respect
 10 to the gradient a of the actual road surface height Lr is known,
 11 a deviation amount ΔDP between the proper value of the vanishing
 12 point parallax DP and the current value can be calculated.

13 First, in case where the vanishing point parallax DP
 14 is an optimum value enough to be able to completely offset the
 15 errors, the gradient value of the calculated road surface height
 16 Lr' (agrees with the the gradient of the actual road surface height
 17 Lr) is a . Accordingly, the gradient a is expressed based on Formula
 18 6 and Formula 7 which have been described as follows:

19 [Formula 9]

$$\begin{aligned} 20 \quad a &= \frac{y1}{z1}, \\ 21 \quad &= \frac{CAH}{KZH} (d1 - DP) - (JV - j1) PWV \\ 22 \end{aligned}$$

23 On the other hand, in case where the vanishing point
 24 parallax is a value DP' which deviates from the proper value DP ,
 25 the gradient a' of the calculated road surface height Lr' is

1 expressed in the following formula:

2 [Formula 10]

$$\begin{aligned} 3 \quad a' &= \frac{y_l}{z_l} \\ 4 \quad &= \frac{CAH}{KZH} (d_l - DP') - (JV - j_l) PWV \\ 5 \end{aligned}$$

6 Eliminating d , j based on the formulas 9 and 10,
7 following formula is obtained:

8 [Formula 11]

$$9 \quad a - a' = \frac{CAH}{KZH} (DP' - DP)$$

11 Transforming the formula 11 to obtain $DP - DP'$,
12 that is, the deviation amount ΔDP of the vanishing point parallax:

13 [Formula 12]

$$\begin{aligned} 14 \quad \Delta DP &= DP - DP' \\ 15 \quad &= \frac{KZH}{CAH} (a' - a) \\ 16 \end{aligned}$$

17 The gradient a of the actual road height L_r is 0. On
18 the other hand, the gradient a' of the calculated road height
19 L_r' can be identified based on the parameter c of the lane marker
20 model L , R ($Y = c \cdot Z + d$) calculated in the recognition section.
21 Similarly to the gradient a' of the calculated road surface height
22 L_r' , when the horizontal deviation of the stereoscopic camera
23 exists, the error caused by the deviation effects on the lane
24 marker model L , R . Hence, letting the mean value of parameters
25 c_L , c_R of the left and right lane marker model L , R up to a

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1 predetermined distance (for example a range from 0 to Z2) be C,
2 it is possible to regard this value C as a gradient a' of the
3 calculated road surface height Lr'. Further, substituting a =
4 0, a' = C into the formula 12, the deviation amount ΔDP of the
5 vanishing point parallax is expressed by the following formula
6 finally:

7 [Formula 13]

$$\Delta DP = \frac{KZH}{CAH} C$$

10 As seen from the formula 13, the result of multiplying
11 the parameter C by a constant (KZH/CAH) is the deviation amount
12 ΔDP of the vanishing point parallax. Hence, by adding the
13 deviation amount ΔDP to the vanishing point parallax DP, the
14 calculated road surface height Lr' can be made identical to the
15 actual road height Lr (a' = a = 0. That is, the error of the parallax
16 d caused by the horizontal deviation of the stereoscopic camera
17 can be eliminated by using the vanishing point parallax DP
18 properly established based on the deviation amount ΔDP calculated
19 according to the formula 13. As a result, even in a case where
20 a horizontal deviation of the stereoscopic camera exists, an
21 accurate distance Z can be calculated by properly establishing
22 the vanishing point parallax DP which is a parallax correction
23 value.

24 The description above is based on a premise that the
25 flat road without up-and-down is always horizontal with respect

1 to Z-axis. However, in practice, an actual road surface height
2 L of the flat road does not always agree with Z-axis due to the
3 affect of the pitching motion of the own vehicle. For example,
4 when the own vehicle directs upward (sky side), the gradient a
5 of the actual road surface height L_r becomes a negative value
6 and when the own vehicle directs downward (ground side), the
7 gradient a of the actual road surface height L_r becomes a positive
8 value. When the gradient a of the actual road height L_r is rendered
9 to be 0 as mentioned before, the deviation amount ΔDP itself has
10 an error due to the effect of pitching. From the view point of
11 improving the accuracy of a calculated distance, it is necessary
12 to properly calculate the gradient a of the actual road surface
13 height L_r .

14 "A vanishing point" is identified based on a two-
15 dimensional(i-j plane) positional information of the left and
16 right lane markers in the reference image and then a gradient
17 a of the actual road surface height L_r is calculated from this
18 "vanishing point". Here, the term "vanishing point" is defined
19 to be an infinitely far point (infinite point), that is, a point
20 where all parallel lines extending in the depth (distance)
21 direction converge at the infinite far image. For example, when
22 a rectangular parallelepiped disposed in a three-dimensional
23 space is mapped through a camera on a two-dimensional plane, the
24 parallel lines constituting the rectangular parallelepiped
25 always meet together at a point. This point of intersection is

1 "a vanishing point". In the vehicle surroundings monitoring
2 apparatus for imaging the frontal scene, this example corresponds
3 to a case where the left and right lane markers on respective
4 road sides run ahead in parallel with each other in the depth
5 (distance) direction of the image. Since the left and right lane
6 markers are in parallel with each other, the left and right lane
7 markers in the picture image are approximated to straight lines
8 respectively, letting the intersection of these lines be a
9 vanishing point V2d (IV2D, JV2D).

10 Specifically, as shown in Fig. 13, a plurality of left
11 white line edges Pedg1 are approximated to a straight line to
12 obtain an approximation line L1 and similarly a plurality of right
13 white line edges Pedg2 are approximated to a straight line to
14 obtain an approximation line L2. In order to raise the accuracy
15 in calculating the vanishing point JV2D, it is preferable that
16 only the white line edges within a specified range of distance
17 (for example, 0 to Z2) are used for calculating the approximation
18 line. The range of distance, if it is too short, the accuracy
19 of the approximation lines L1, L2 and if it is too long, the amount
20 of calculations increases or there is a decreasing chance of the
21 lane marker projected on the line, that is, it is difficult to
22 create the condition of lane marker suitable for calculating the
23 vanishing point JV2D. The intersection of these approximation
24 lines L1, L2 is a vanishing point V2d. The gradient α of the actual
25 road surface height L_r can be identified if the j -coordinate JV2D

1 is known. Accordingly, in the description hereinafter, the
2 j-coordinate JV2D of the vanishing point V2d is referred to as
3 "actual vanishing point" for the purpose of discriminating from
4 the established vanishing point JV.

5 Fig. 9 is a diagram showing the relationship between
6 the actual road surface height L_r and the calculated road surface
7 height L_r' . The stereoscopic camera is mounted on the vehicle
8 in such a manner that the vanishing line L_v connecting the
9 installation height CAH of the camera and the actual vanishing
10 point JV2D is in parallel with the actual road surface height
11 L_r . In case where the own vehicle generates pitchings, the
12 gradient of the actual road surface height L_r varies and at the
13 same time the gradient of the vanishing line L_v also varies. That
14 is, regardless of the existence or nonexistence of the pitching
15 of the own vehicle, the gradient of the actual road surface height
16 L_r always agrees with that of the vanishing line L_v (both gradients
17 are a). That is to say, even in case where the vehicle has a pitching
18 motion, the vanishing line L_v is always in parallel with the actual
19 road surface height L_r . Consequently, the gradient of the actual
20 road surface height L_r can be identified by obtaining the gradient
21 a of the vanishing line L_v . If this gradient a is known, the
22 vanishing point parallax DP can be calculated by transforming
23 the formula as follows.

24 First, after substituting the vanishing point JV2D
25 into a variable j of the formula 3, obtaining the gradient (Y/Z)

1 on Z-Y plane:

2 [Formula 14]

3
$$a = (JV2D - JV)PWV$$

4 As seen from the formula, if the actual vanishing point
5 JV2D is identified, the gradient a (corresponding to the gradient
6 of the actual road surface Lr) height of the vanishing line Lv
7 is identified unconditionally.

8 Substituting the formula 14 into the formula 12,
9 finally the following formula can be obtained:

10 [Formula 15]

11
$$\Delta DP = \frac{KZH}{CAH} C - \frac{KZH}{CAH} (JV2D - JV)PWV$$

12
13 The formula 15 is obtained by subtracting a portion
14 affected by the pitching as a correction term from the formula
15 13. The correction term is obtained by multiplying the product
16 of substituting the established vanishing point JV from the actual
17 vanishing point JV2D by a predetermined constant KZH/CAH.
18 Accordingly, if the current value of the vanishing point parallax
19 DP is added by the deviation amount ΔDP , regardless of the
20 existence or nonexistence of pitching of the own vehicle, the
21 gradient a' of the calculated road surface height Lr' always
22 agrees with the gradient a of the actual road surface height Lr.
23 This means that the error caused by the horizontal deviation of
24 the stereoscopic camera is offset by the vanishing point parallax
25 DP and the distance Z is calculated as being actually measured.

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1 The effect of pitching of the own vehicle exerts not only on the
2 gradient a of the vanishing line L_v (and the actual road surface
3 height L_r) but also on the gradient a' of the calculated road
4 surface height L_r' . However, the deviation amount ΔDP is
5 calculated such that the effect of pitching with respect to the
6 gradient a and the effect of pitching with respect to the gradient
7 a' are mutually offset (refer to the formula 12). Accordingly,
8 an accurate deviation amount ΔDP
9 can be calculated without being affected by pitching of the
10 vehicle.

11 Next, the detailed description of the parallax
12 correction according to this embodiment will be made by reference
13 to flowcharts shown in Fig. 2 and Fig. 3.

14 The correction calculating section 13 updates the
15 value of the vanishing point parallax DP according to a series
16 of steps and this value is fed back to the recognition section
17 10. The flowcharts are executed repeatedly per cycle.

18 First, at a step 1, the correction calculating section
19 13 reads white line edges P_{edge} and lane marker models L, R
20 calculated in the recognition section 10 of a reference image.
21 Next, at steps 2 through 6, it is evaluated whether or not the
22 reference image is in a suitable condition for calculating the
23 vanishing point $JV2D$. First, at a step 2, it is judged whether
24 or not the left and right lane markers exist in the reference
25 image which is an object of calculating the vanishing point $JV2D$.

1 That is, this can be judged by investigating whether or not the
2 left and right lane marker models L, R have been calculated in
3 the recognition section 10. Further, this may be judged by
4 investigating whether or not the left white line edges Pedge1
5 and the right white line edges Pedge2 have been calculated. At
6 the step 2, in case where the judgment is negative, that is, in
7 case where the left and right lane markers exist nowhere, since
8 mutually parallel lines have not extracted, the vanishing point
9 JV2D can be calculated. Hence, in order to maintain the safety
10 of the control, the program goes to RETURN without changing the
11 current value of the vanishing point parallax DP and the execution
12 of this flowchart in the present cycle finishes. On the other
13 hand, at the step 2, in case where the judgment is positive, the
14 program goes to a step 3.

15 At the step 3, the reliability of the left and right
16 lane markers are verified. Specifically, following two things
17 are evaluated.

18 1. In case where the difference between the position of
19 the lane marker in the previous cycle and the position of the
20 lane marker in the present cycle is greater than a specified value,
21 it is judged that the lane marker has a low reliability.
22 Specifically, in case where the position of the white line edge
23 Pedge detected in the previous cycle largely deviates from the
24 position of the white line edge Pedge detected in the present
25 cycle, the lane marker is judged to have a low reliability.

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1 2. It is verified how far the lane marker extends in the
2 depth direction of an image. The lane marker has at least some
3 extent of length. Accordingly, taking the shift of the lane
4 marker between frames into consideration, in case where the lane
5 marker does not extend longer than a specified length, it is judged
6 that this lane marker has a low reliability.

7 After that, at a step 4, it is judged whether or not
8 the lane marker is reliable and only when it is judged to be
9 reliable, the program goes to a step 5. On the other hand, when
10 it is judged that the lane marker can not be relied, the program
11 goes to RETURN without changing the value of the vanishing point
12 parallax DP.

13 At the step 5, the linearity of the lane marker is
14 evaluated. In order to calculate an accurate vanishing point JV2D,
15 it is necessary that the left and right lane markers extend in
16 line. That is, it is impossible to calculate an accurate vanishing
17 point JV2D from curved lane markers. Hence, only in case where
18 it is judged at a step 6 that the lane marker is a straight line,
19 The program goes to a step 7 and otherwise the program goes to
20 RETURN without changing the value of the vanishing point parallax
21 DP.

22 The linearity of the lane marker can be evaluated for
23 example based on a lane marker model (curve function $X = f(Z)$)
24 calculated in the recognition section 10. Describing by reference
25 to Fig. 11, first a gradient A1 (mean value of gradients a_L , a_R

1 of left and right lane markers L, R, respectively) of the curve
2 function within a specified distance range (for example 0 to Z2)
3 on Z-X plane, is calculated. The gradient A1 is a mean value of
4 a gradient a1 in the first segment and a gradient a2 in the second
5 segment. Next, a gradient A2 of the curve function within a
6 specified distance range located ahead (for example Z2 to Z4)
7 is calculated. The gradient A2 is is a mean value of a gradient
8 a3 in the third segment and a gradient a4 in the fourth segment.
9 Then, a difference (absolute value) between the gradients A1 and
10 A2 is obtained. If the difference is smaller than a threshold
11 value, it is judged that the lane marker is a straight line.

12 Steps after the step 7 are related to an up-dating of
13 the vanishing point parallax DP. First, at the step 7, an
14 approximation line L1 of a plurality of left white line edges
15 Pedge1 existing within a specified range (for example, 0 to Z2)
16 is calculated according to the least square method (refer to Fig.
17 13). Similarly, an approximation line L2 of a plurality of left
18 white line edges Pedge2 existing within that range is calculated
19 according to the least square method.

20 At a step 8 following the step 7, as shown in Fig. 13,
21 an point of intersection of the approximation lines L1, L2 is
22 determined to calculate the vanishing point JV2D of the reference
23 image. Further, at a step 9, a gradient a of the vanishing line
24 Lv is calculated by substituting the vanishing point JV2D
25 calculated at the step 8 into the formula 14. As described above,

1 obtaining the gradient a of the vanishing point L_v just means
2 calculating a gradient a of the actual road surface height.

3 Next, at a step 10, a gradient a' of the calculated
4 road surface height L_r' is calculated. As mentioned before, the
5 gradient a' is a parameter C calculated from the left and right
6 lane marker models L , R .

7 At a step 11, the correction of parallax, namely, an
8 up-dating of the vanishing point parallax DP is performed. Fig.
9 4 is a flowchart showing steps for up-dating the vanishing point
10 parallax DP . First, at a step 21, a deviation amount ΔDP is
11 calculated by substituting the parameter C and the vanishing point
12 $JV2D$ into the formula 15.

13 At a step following the step 21, in order to secure
14 the safety of control, the up-dating process of the vanishing
15 point parallax DP is performed using a proportional control. That
16 is, the value of the vanishing point parallax DP is up-dated by
17 adding an value the deviation amount ΔDP calculated at the step
18 21 and multiplied by a proportional constant k ($0 < k < 1$) to the
19 present value of the vanishing point parallax DP . Further, at
20 a step 23, the up-dated vanishing point parallax DP is outputted
21 to the recognition section 10 and the execution of this flowchart
22 in the present cycle finishes.

23 The aforesaid flowchart is carried out in consecutive
24 cycles. Therefore, even if such a situation that the vanishing
25 point parallax DP is out of a proper value, occurs, the vanishing

1 point parallax DP gradually comes close to a proper value by
2 carrying the flowchart out repeatedly. Hence, since the error
3 of the distance Z caused by the horizontal deviation of the
4 stereoscopic camera is gradually offset, the gradient a' of the
5 calculated road surface Lr' converges to the gradient a of the
6 actual road surface height Lr .

7 According to the steps described above, the
8 optimization of the vanishing point parallax DP proceeds in
9 parallel with the normal monitoring control and even in case where
10 the horizontal deviation of the stereoscopic camera occurs, the
11 distance can be always calculated accurately. Accordingly, even
12 in case where the position of the stereoscopic camera is changed
13 from the initial position by aged deterioration of the camera
14 or shocks applied to thereto, highly reliable distance
15 information can be obtained stably. The highly reliable distance
16 information provides surroundings monitorings with a
17 reliability.

18 Further, the left and right lane markers existing on
19 both sides of the road are used as mutually parallel lines
20 extending in the depth direction and needed for the calculation
21 of the vanishing point JV2D of the reference image. In this
22 embodiment, it is judged whether or not the lane marker is suitable
23 for calculating the vanishing point JV2D by evaluating the
24 linearity of the lane marker or the positional relationship of
25 the lane marker between frames. Further, only when it is judged

1 that the lane marker is suitable, the value of the vanishing point
2 parallax DP or the parallax correction value is changed. Hence,
3 since an inappropriate vanishing point JV2D can be prevented from
4 being calculated, this providing further stable, highly reliable
5 distance information.

6 In the above description, the updating of the vanishing
7 point parallax is performed by the proportional control, however,
8 the updating may be performed by the statistic control. For
9 example, preparing a histogram composed of 1000 samples of the
10 deviation amount ΔDP of the vanishing point parallax, a most
11 frequently observed value may be used as a deviation amount Δ
12 DP. This up-dating process according to the statistical control
13 can be can be applied to a second, third, and fourth embodiments.
14 (Second embodiment)

15 According to the second embodiment, the parallax
16 correction value DP is updated based on the comparison
17 relationship between the gradient a of the actual road surface
18 height L_r (that is, gradient a of the vanishing line L_v) and the
19 gradient a' (that is, the parameter C identified from the lane
20 marker models L, R) of the calculated road surface height L_r' .
21 The steps of up-dating are the same as those shown in the
22 flowcharts of Figs. 2 and 3. A portion different from the first
23 embodiment is the step 11 of Fig. 3, that is, a part where the
24 distance calculation parameter is updated.

25 Fig. 5 is a flowchart showing up-dating steps of the

1 parallax correction value DP according to the second embodiment.
2 First, at a step 31, it is judged whether or not the product of
3 subtracting the gradient a of the actual road surface height L_r
4 from the gradient a' of the calculated road surface height L_r' ,
5 is larger than a positive threshold value TH. In case where the
6 positive judgment (YES) is made at the step 31, the program goes
7 to a step 34 where a specified value α is added to the present
8 value of the vanishing point parallax DP and at a step 36 a larger
9 vanishing point parallax DP than a previous one is outputted to
10 the recognition section 10. On the other hand, in case of NO at
11 the step 31, the program goes to a step 32.

12 At the step 32, it is judged whether or not the
13 subtraction of the gradient a from the gradient a' is smaller
14 than a negative threshold value $-TH$. In case of Yes at the step
15 32, at a step 34, the specified α is reduced from the present
16 value of the vanishing point parallax DP. Accordingly, at a step
17 36, a smaller vanishing point parallax DP than the previous one
18 is outputted to the recognition section 10. On the other hand,
19 in case of NO at the step 32, that is, in case where the subtraction
20 $a'-a$ is within a range from the negative threshold value $-TH$ to
21 the positive threshold value TH, the value DP is not changed based
22 on the judgment that the vanishing point parallax DP is proper
23 to maintain the control stability.

24 The relationship between the difference of the
25 gradient a' of the calculated road surface height L_r' from the

1 gradient a of the actual road surface height L_r and the distance
2 Z , will be described by reference to Fig. 10.

3 Letting the distance to a road surface point P_1 be z_1 ,
4 and letting the gradient of the actual road surface height L_r
5 passing through the road surface point P_1 be a , when the distance
6 z_1' (containing an error) is calculated, a road surface point
7 P_1' on Z-X plane appears on a line m connecting the installation
8 height of the camera CAH and the original road surface point P_1 .
9 Accordingly, it is understood that as the calculated distance
10 z_1' becomes smaller than the actual distance z_1 , the gradient
11 a' of the calculated road surface height L_r' becomes larger than
12 the gradient a of the actual road surface height L_r . From this
13 point of view, in case of $a' > a$, the calculated distance z_1' should
14 be adjusted so as to increase and for that purpose the value of
15 the vanishing point parallax DP should be increased (see the
16 formula 2). Inversely, in case of $a' < a$, the calculated distance
17 z_1' should be adjusted to become small and for this purpose the
18 value of the vanishing point parallax DP should be decreased.

19 Even in case where the vanishing point parallax DP
20 is not proper, that value gradually comes close to the proper
21 value by carrying out the aforesaid flowchart in respective cycles.
22 Hence, since the error of the distance Z caused by the horizontal
23 deviation of the stereoscopic camera is gradually offset by the
24 vanishing point parallax DP, the gradient a' of the calculated
25 road surface height L_r' converges to the gradient a of the actual

1 road surface height L_r . As a result, also in this embodiment,
2 a highly accurate distance can be obtained stably. Further, as
3 a result of performing the monitoring control based on thus
4 obtained distance, the reliability of the vehicle surroundings
5 monitoring can be enhanced.

6 (Third embodiment)

7 The feature of this embodiment is that an affine
8 parameter SHFT1 (shift in horizontal direction) in the affine
9 transformation is updated according to the difference between
10 the gradient a' of the calculated road surface height L_r' and
11 the gradient a of the actual road surface height L_r .

12 Fig. 6 is a block diagram showing the construction of
13 a stereoscopic type vehicle surroundings monitoring apparatus
14 according to the third embodiment. The block diagram is the same
15 as that of Fig. 1 except for that the affine parameter SHFT1
16 calculated in the correction calculating section 13 is fed back
17 to the correction circuit 5. Therefore, the components of the
18 block diagram which are identical in both embodiments are denoted
19 by identical reference numbers and are not described in detail.

20 The steps of updating the affine parameter SHFT1 are
21 the same as the flowcharts shown in Figs. 2 and 3 in the first
22 embodiment. What differs from the first embodiment is a step 11
23 of Fig. 3 concerning the updating of parameters for calculating
24 the distance.

25 Fig. 7 is a flowchart showing steps for up-dating an

1 affine parameter SHFT1 (parallax correction value) which
2 represents the shift in the horizontal direction. First, at a
3 step 41, it is judged whether or not the product of subtracting
4 the gradient a of the actual road surface height L_r from the
5 gradient a' of the calculated road surface height L_r' , is larger
6 than a positive threshold value TH. In case where the positive
7 judgment (YES) is made at the step 41, the program goes to a step
8 44 where a specified value β is subtracted from the present value
9 of the affine parameter SHFT1 and at a step 46 a smaller affine
10 parameter SHFT1 than a previous one is outputted to the correction
11 circuit 5. On the other hand, in case of NO at the step 41, the
12 program goes to a step 42.

13 At the step 42, it is judged whether or not the
14 subtraction $a'-a$ is smaller than a negative threshold value -TH.
15 If the judgment is YES at the step 42, the specified value β is
16 added to the present value of the affine parameter SHFT1 at a
17 step 45 and a larger affine parameter SHFT1 than a previous one
18 is outputted to the correction circuit 5 (step 46). On the other
19 hand, if the judgment is NO at the step 42, that is, if the
20 subtraction $a'-a$ is within a range from the negative threshold
21 value -TH to the positive threshold value TH, it is judged that
22 the affine parameter SHFT1 is proper to maintain the control
23 stability and this value is not changed.

24 As described in the second embodiment, in case of $a' > a$,
25 the calculated distance $z1'$ should be adjusted so as to increase,

1 in other words, the parallax d should be reduced. For that purpose,
2 the value of the affine parameter SHFT1 should be established
3 to be smaller than the previous one. That is, the affine parameter
4 SHFT1 is updated such that the shift amount in the horizontal
5 direction becomes small. Inversely, in case of $a' < a$, the
6 calculated distance $z1'$ should be adjusted to become small, in
7 other words, the parallax d should be increased. For this purpose,
8 the value of the affine parameter SHFT1 should be established
9 to be larger than the previous one. That is, the affine parameter
10 SHFT1 is up-dated such that the shift amount in the horizontal
11 direction becomes large.

12 As described before, the feedback adjustment of the
13 affine parameter SHFT1 (representing the shift in the horizontal
14 direction) is made in parallel with the monitoring control. As
15 a result, even in case where the horizontal deviation of the
16 stereoscopic camera occurs, the affect of the deviation is offset
17 by the affine parameter SHFT1, thereby an accurate parallax d
18 can be obtained. As a result, highly accurate distance information
19 can be obtained, whereby the reliability of the vehicle
20 surroundings monitoring can be enhanced.

21 (Fourth embodiment)

22 This embodiment relates to the method of regulating
23 the established vanishing point V (IV, JV) used in the
24 transformation formulas 3 and 4 for calculating coordinates (X,
25 Y) showing the position of an object by utilizing the vanishing

1 point V2d (IV2D, JV2D) which is shown in Fig. 13.

2 Fig. 14 is a block diagram showing a stereoscopic type
3 vehicle surroundings monitoring apparatus according to a fourth
4 embodiment. In the correction calculating section 13, the
5 established vanishing point V(IV, JV) is updated based on the
6 vanishing point V2d(IV2D, JV2D) in the reference image and the
7 calculated vanishing point IV, JV is outputted to the recognition
8 section 10. Except for this section, the block diagram is
9 identical to that of Fig. 1. Therefore, identical reference
10 numbers denoted
11 in both embodiments are not described in detail.

12 Next, steps for updating the established vanishing
13 point IV, JV will be described. First, according to the steps
14 from the step 1 to the step 6 shown in the flowchart of Fig. 2,
15 it is judged whether or not the reference image is in a condition
16 suitable for calculating the vanishing point J2d (IV2D, JV2D).

17 Fig. 15 is a flowchart according to this embodiment
18 continued from Fig. 2 and related to the updating process of the
19 established vanishing point V (IV, JV). First, at a step 51,
20 an approximation line L1 of a plurality of left white line edges
21 Pedge1 existing within a specified distance range (for example,
22 0 to Z2) is calculated by the least square method (see Fig. 13).
23 Also, in the same manner, at the step 51, an approximation line
24 L2 of a plurality of right white line edges Pedge2 existing within
25 the distance range is calculated by the least square method. After

1 that, the program goes to a step 52 where a point of intersection
 2 of both approximation lines L1, L2, that is, a vanishing point
 3 J2d (IV2D, JV2D) of the reference image is calculated.

4 At a step 53 following the step 52, the established
 5 vanishing point V (IV, JV) which is employed in the formulas 3
 6 and 4, is updated. First, the present value of an i coordinate
 7 value IV of the established vanishing point V is compared with
 8 an i coordinate value IV2D calculated at the step 52 and based
 9 on the result of the comparison, the vanishing point IV is updated
 10 by the following proportional control:

11 [Updating of vanishing point IV]

12 In case of $IV - IV2D > TH$ $IV \leftarrow IV - \gamma$

13 In case of $IV - IV2D < -TH$ $IV \leftarrow IV + \gamma$

14 In case of $|IV - IV2D| \leq TH$ $IV \leftarrow IV$

15 where γ is a constant ($0 < \gamma < 1$).

16 That is, in case where the established vanishing point
 17 IV is larger than the vanishing point IV2D identified from the
 18 left and right lane markers in the image, this case means that
 19 the established vanishing point IV deviates rightward in the
 20 horizontal direction of the image. In this case, the established
 21 vanishing point IV is shifted leftward by a specified amount by
 22 subtracting the constant γ from the present value of the
 23 established vanishing point IV. On the other hand, in case where
 24 the established vanishing point IV is smaller than the vanishing
 25 point IV2D, this case means that the established vanishing point

1 IV deviates leftward in the horizontal direction of the image.
 2 In this case, the established vanishing point IV is shifted
 3 rightward by a specified amount by adding the constant γ to the
 4 present value of the established vanishing point IV. Further,
 5 in order to make the control stable, in case where the difference
 6 (absolute value) between both is within a specified value TH,
 7 the established vanishing point IV is not changed.

8 Similarly, the vanishing point JV is updated according
 9 to the following proportional control by comparing the present
 10 value of the j coordinate value JV of the established vanishing
 11 point V with the j coordinate value JV2D of the calculated
 12 vanishing point V2d.

13 [Updating of vanishing point JV]

14 In case of $JV - JV2D > TH$ $JV \leftarrow JV - \delta$

15 In case of $JV - JV2D < -TH$ $JV \leftarrow JV + \delta$

16 In case of $|JV - JV2D| \leq TH$ $JV \leftarrow JV$

17 where δ is a constant ($0 < \delta < 1$).

18 That is, in case where the established vanishing point
 19 JV is larger than the vanishing point JV2D identified from the
 20 left and right lane markers in the image, this case means that
 21 the established vanishing point JV deviates upward in the vertical
 22 direction of the image. In this case, the established vanishing
 23 point JV is shifted downward by a specified amount by subtracting
 24 the constant δ from the present value of the established
 25 vanishing point JV. On the other hand, in case where the

1 established vanishing point JV is smaller than the vanishing point
2 JV2D, this case means that the established vanishing point JV
3 deviates downward in the vertical direction of the image. In this
4 case, the established vanishing point JV is shifted upward by
5 a specified amount by adding the constant δ to the present value
6 of the established vanishing point JV. Further, in order to make
7 the control stable, in case where the difference (absolute value)
8 between both is within a specified value TH, the established
9 vanishing point JV is not changed.

10 At a step 54 following the step 53, the vanishing point
11 V (IV, JV) is outputted to the recognition section 10.

12 When the established vanishing point (IV, JV) is not
13 proper, that value gradually comes close to a proper value by
14 carrying out the aforesaid flowchart in each cycle. Specifically,
15 this flow of control is performed in real time in parallel with
16 the normal monitoring control and even when errors are caused
17 in the present value of the established vanishing point (IV, JV),
18 that value containing errors gradually converges to an optimum
19 value. As a result, the position (X, Y) of an object can be
20 calculated with high precision, thereby the reliability of
21 vehicle surroundings monitoring can be enhanced.

22 [Application to miscellaneous monitoring apparatuses]

23 In the embodiments described before, the method of
24 calculating the vanishing point using the left and right lane
25 markers projected on the image has been explained. This method

1 is based on a general tendency that, in case of monitoring ahead
2 of the vehicle, there exist lane markers extending in the front
3 (depth) direction of the vehicle on left and right sides of the
4 road and these lane markers are parallel with each other. In the
5 specification, a linear object like lane markers which extend
6 in the front direction in parallel with each other, and which
7 is a base for calculating an vanishing point, is referred to as
8 "reference object". The present invention can be broadly applied
9 to miscellaneous monitoring system using picture images where
10 the "reference object" is projected.

11 Taking an example, in case of applying to an indoor
12 robot able to recognize surrounding situations, a boundary line
13 constituted by a wall and a floor can be used as a "reference
14 object". Fig. 16 is an example of an image taken by an indoor
15 robot. Normally, in many cases, the boundary line of a left wall
16 and a floor and the boundary line of a right wall and a floor
17 extend in the depth direction of the image in parallel with each
18 other. Accordingly, the correction of the vanishing point or the
19 correction of distance can be done by using the left and right
20 boundary lines.

21 Below, the outline of steps for adjusting the vanishing
22 point making use of boundary lines.

23 First, a plurality of lines L1, L2 are detected based
24 on the reference image. In the same way as the condition of white
25 line edges described before, conditions with respect to

1 brightness edges or parallax at the boundary portion between wall
2 and floor are established before hand. Further, portions
3 satisfying these conditions are recognized as boundary lines in
4 the image and the linearity of these boundary lines is evaluated.
5 After these processes, approximation lines L1, L2 are calculated.
6 In another way, lines L1, L2 as "reference object" may be
7 calculated by extracting dots (edge pixels at boundary portions)
8 for forming lines in the image, using well-known Huff
9 transformation and the like.

10 Next, it is judged that the lines L1, L2 are
11 approximately parallel with each other based on the distance image.
12 As described before, the position of respective areas
13 constituting lines L1, L2 in real space can be identified based
14 on the distance image. Accordingly, in case where two lines L1,
15 L2 are detected, the parallelism of these lines L1, L2 is judged
16 using the known method.

17 In case where the lines L1, L2 are parallel, a vanishing
18 point is calculated from the point of intersection of these lines
19 L1, L2. Further, a gradient a of lines L1, L2 is calculated
20 respectively and coordinates of the vanishing point are
21 calculated based on the gradient. Finally, the value of the
22 vanishing point parallax is adjusted such that the coordinates
23 of two calculated vanishing points agree with each other.

24 Further, taking another example, in case of applying
25 to the system for monitoring frontal situations of a railway

1 rolling stock, left and right railways can be utilized as
2 "reference object". Fig. 17 is an example of the image projecting
3 the front scenery of the railway rolling stock. The left and right
4 railways extend in the depth direction in parallel with each other.
5 Accordingly, two parallel lines L1, L2 can be identified by making
6 use of the left and right railways as "reference object", thereby
7 the vanishing points can be adjusted by the method described
8 above.

9 In summary, according to the present invention,
10 parameters with respect to the calculation of three-dimensional
11 information such as distance information, for example, a
12 vanishing point parallax DP, an affine parameter SHFTI, a
13 vanishing point (IV, JV) and the like, are corrected based on
14 the actual vanishing point calculated from the left and right
15 lane markers in the image. Accordingly, in case where a positional
16 deviation of the stereoscopic camera occurs, since the parameters
17 values are automatically adjusted so as to offset errors caused
18 by that positional deviation, three-dimensional information (for
19 example, distance information) with high accuracy can be obtained
20 stably.

21 While the presently preferred embodiments of the
22 present invention have been shown and described, it is to be
23 understood that these disclosures are for the purpose of
24 illustration and that various changes and modifications may be
25 made without departing from the scope of the invention as set

1 forth in the appended claims.

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1 WHAT IS CLAIMED IS:

2 1. A distance correcting apparatus of a surroundings
3 monitoring system, comprising:

4 a stereo imaging means for stereoscopically taking a
5 pair of images;

6 a parallax calculating means for calculating a
7 parallax based on said pair of images;

8 a distance calculating means for calculating a
9 distance to an object based on said parallax and a first parameter
10 for correcting said distance;

11 an approximation line calculating means for
12 calculating a plurality of approximation lines extending in the
13 distance direction in parallel with each other based on said
14 images;

15 a vanishing point calculating means for calculating
16 a vanishing point of said images from a point of intersection
17 of said approximation lines; and

18 a parameter correcting means for correcting said
19 first parameter based on said vanishing point.

20

21 2. The apparatus according to claim 1, further
22 comprising:

23 a reference object detecting means for detecting a
24 plurality of reference objects extending in the distance
25 direction in parallel with each other from a scenery projected

1 in said images and for identifying a position of said reference
2 objects in an image plane of said images.

3
4 3. The apparatus according to claim 2, wherein
5 said vanishing point calculating means calculates an
6 approximation line in said image plane for respective reference
7 objects, when a plurality of reference objects are detected by
8 said reference objects detecting means.

9
10 4. The apparatus according to claim 2, wherein
11 said reference objects are lane markers on a road
12 projected in said images and when left and right lane markers
13 are detected on said road, said vanishing point calculating means
14 calculates an approximation line in said image plane for said
15 respective left and right lane markers.

16
17 5. The apparatus according to claim 4, wherein
18 said vanishing point calculating means calculates said
19 approximation line based on said left and right lane markers
20 existing within a specified distance range.

21
22 6. The apparatus according to claim 4, wherein
23 said reference object detecting means calculates a
24 lane marker model expressing the change of a road surface height
25 with respect to distance and said first parameter correcting means

1 identifies a condition of change of an actual road surface height
2 based on said vanishing point calculated by said vanishing point
3 calculating means, identifies a condition of change of a
4 calculated road surface height based on said lane marker model
5 calculated by said reference object detecting means, and corrects
6 said first parameter so that said condition of change of said
7 calculated road surface height comes close to said condition of
8 change of said actual road surface height.

9

10 7. The apparatus according to claim 4, wherein
11 said reference object detecting means calculates a
12 lane marker model expressing the change of a road surface height
13 with respect to distance and said parameter correcting means
14 identifies a first gradient indicating the change of a road
15 surface height with respect to distance based on said vanishing
16 point calculated by said vanishing point calculating means,
17 identifies a second gradient indicating the change of a road
18 surface height with respect to distance based on said lane marker
19 model calculated by said reference object detecting means, and
20 corrects said first parameter so that a deviation of said second
21 gradient with respect to said first gradient becomes small.

22

23 8. The apparatus according to claim 4, wherein
24 said vanishing point calculating means judges whether
25 or not a lane marker projected in said images is a straight line

1 and in case where it is judged that said lane marker is a straight
2 line, calculates said vanishing point of said images.

3

4 9. The apparatus according to claim 8, wherein
5 said vanishing point calculating means evaluates a
6 time-versus change of the position of a lane marker projected
7 in said images, if said time-versus change is small, judges that
8 said lane marker has a high reliability as lane markers, and
9 calculates said vanishing point in said images.

10

11 10. The apparatus according to claim 9, wherein
12 said parameter is a vanishing point parallax.

13

14 11. A distance correcting apparatus of a surroundings
15 monitoring system, comprising:

16 a stereo imaging means for stereoscopically taking a
17 pair of images;

18 a transforming means for geometrically transforming
19 said pair of images based on a second parameter indicating a
20 transference in the horizontal direction;

21 a parallax calculating means for calculating a
22 parallax based on said pair of images outputted from said
23 transforming means;

24 a distance calculating means for calculating a
25 distance to an object based on said parallax;

1 a vanishing point calculating means for calculating
2 a plurality of approximation lines extending in the distance
3 direction in parallel with each other and calculating a vanishing
4 point of said images from a point of intersection of said
5 approximation lines; and

6 a parameter correcting means for correcting said
7 second parameter based on said vanishing point.

8

9 12. The apparatus according to claim 11, further
10 comprising:

11 a reference object detecting means for detecting a
12 plurality of reference objects extending in the distance
13 direction in parallel with each other from a scenery projected
14 in said images and for identifying a position of said reference
15 objects in an image plane of said images.

16

17 13. The apparatus according to claim 12, wherein

18 said vanishing point calculating means calculates an
19 approximation line in said image plane for respective reference
20 objects, when a plurality of reference objects are detected by
21 said reference objects detecting means.

22

23 14. The apparatus according to claim 12, wherein

24 said reference objects are lane markers on a road
25 projected in said images and when left and right lane markers

1 are detected on said road, said vanishing point calculating means
2 calculates an approximation line in said image plane for said
3 respective left and right lane markers.

4

5 15. The apparatus according to claim 14, wherein
6 said vanishing point calculating means calculates said
7 approximation line based on said left and right lane markers
8 existing within a specified distance range.

9

10 16. The apparatus according to claim 14, wherein
11 said reference object detecting means calculates a
12 lane
13 marker model expressing the change of a road surface height with
14 respect to distance and said first parameter correcting means
15 identifies a condition of change of an actual road surface height
16 based on said vanishing point calculated by said vanishing point
17 calculating means, identifies a condition of change of a
18 calculated road surface height based on said lane marker model
19 calculated by said reference object detecting means, and corrects
20 said first parameter so that said condition of change of said
21 calculated road surface height comes close to said condition of
22 change of said actual road surface height.

23

24 17. The apparatus according to claim 14, wherein
25 said reference object detecting means calculates a

1 lane marker model expressing the change of a road surface height
2 with respect to distance and said parameter correcting means
3 identifies a third gradient indicating the change of a road
4 surface height with respect to distance based on said vanishing
5 point calculated by said vanishing point calculating means,
6 identifies a fourth gradient indicating the change of a road
7 surface height with respect to distance based on said lane marker
8 model calculated by said reference object detecting means, and
9 corrects said third parameter so that a deviation of said fourth
10 gradient with respect to said third gradient becomes small.

11

12 18. The apparatus according to claim 14, wherein
13 said vanishing point calculating means judges whether
14 or not a lane marker projected in said images is a straight line
15 and in case where it is judged that said lane marker is a straight
16 line, calculates said vanishing point of said images.

17

18 19. The apparatus according to claim 18, wherein
19 said vanishing point calculating means evaluates a
20 time-versus change of the position of a lane marker projected
21 in said images, if said time-versus change is small, judges that
22 said lane marker has a high reliability as lane markers, and
23 calculates said vanishing point in said images.

24

25 20. A vanishing point correcting apparatus of a surroundings

1 monitoring system for taking images of a scenery in front of an
2 own vehicle and for obtaining a three-dimensional information
3 of an object projected in said images by making use of an
4 established vanishing point established beforehand, comprising:
5 reference object detecting means for detecting lane
6 markers on a road projected in said images and for identifying
7 a position of said lane markers on an image plane of said images;
8 vanishing point calculating means, when a left and
9 right lane marker is detected on said road and it is judged that
10 said lane marker projected in said images is a straight line,
11 for calculating an approximation line in said image plane for
12 said respective left and right lane markers and for calculating
13 a vanishing point from a point of intersection of said
14 approximation lines; and
15 a vanishing point correcting means for correcting said
16 vanishing point so that said established vanishing point comes
17 close to said vanishing point calculated by said vanishing point
18 calculating means.
19
20 21. The apparatus according to claim 20, wherein
21 said vanishing point calculating means evaluates a
22 time-versus change of the position of a lane marker projected
23 in said images, if said time-versus change is small, judges that
24 said lane marker has a high reliability as lane markers, and
25 calculates said vanishing point in said images.

ABSTRACT

1
2 A distance correcting apparatus of a surroundings
3 monitoring system includes a stereo imaging means for
4 stereoscopically taking a pair of images of a frontal scenery,
5 a parallax calculating means for calculating a parallax based
6 on the pair of images, a distance calculating means for
7 calculating a distance to an object based on the parallax and
8 a parameter for correcting distance, an approximation line
9 calculating means for calculating a plurality of approximation
10 lines extending in the distance direction in parallel with each
11 other based on the images, a vanishing point calculating means
12 for calculating a vanishing point of the images from a point of
13 intersection of the approximation lines and a parameter
14 correcting means for correcting the parameter based on the
15 calculated vanishing point.
16

FIG. 2

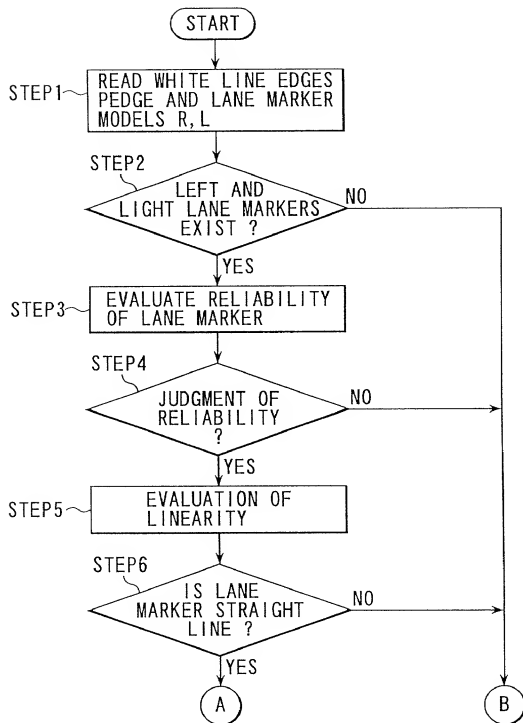


FIG. 3

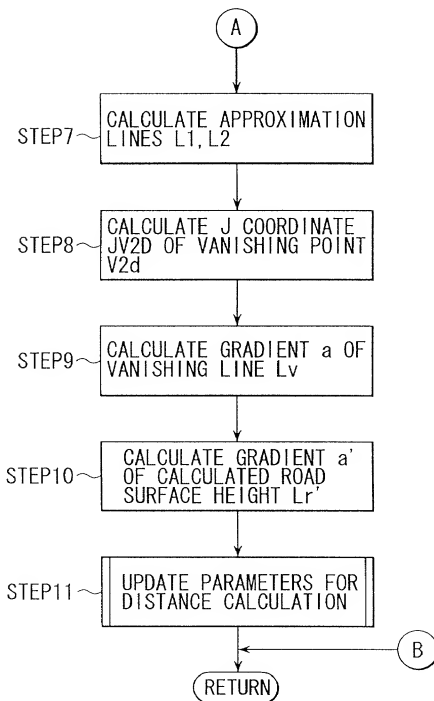


FIG. 4

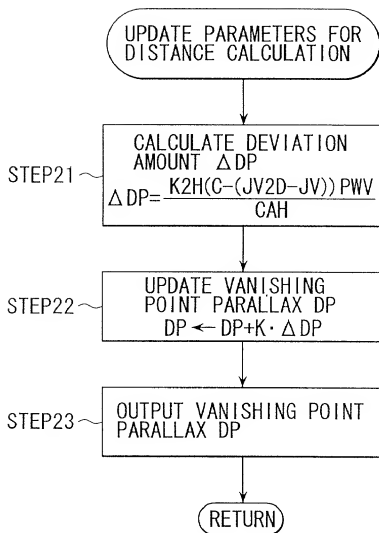


FIG. 5

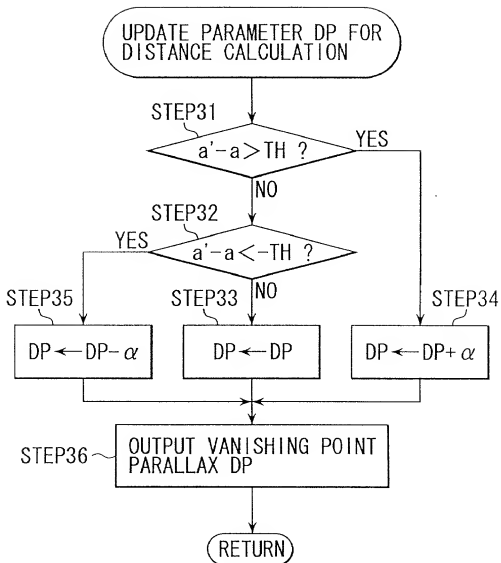


FIG. 6

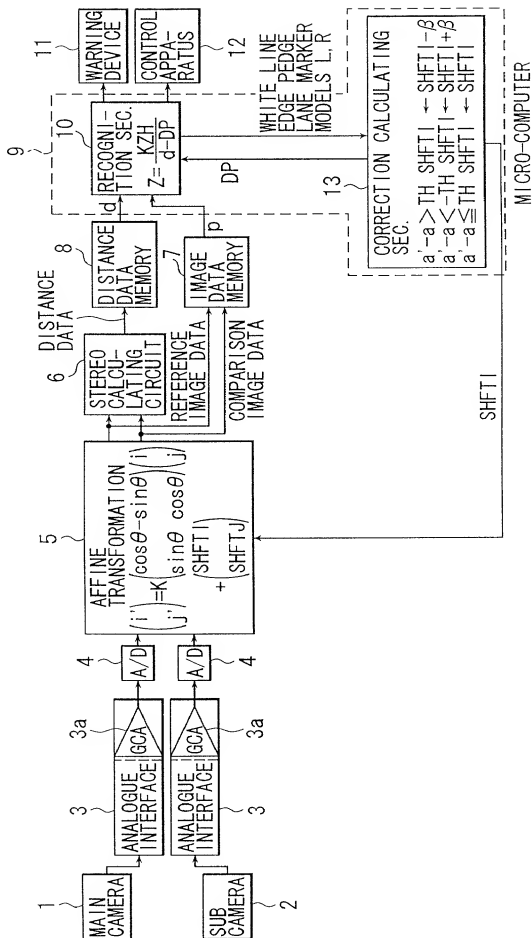


FIG. 7

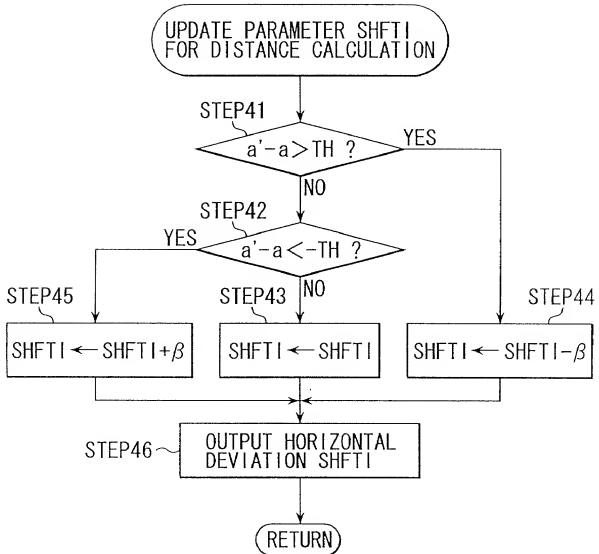


FIG. 8

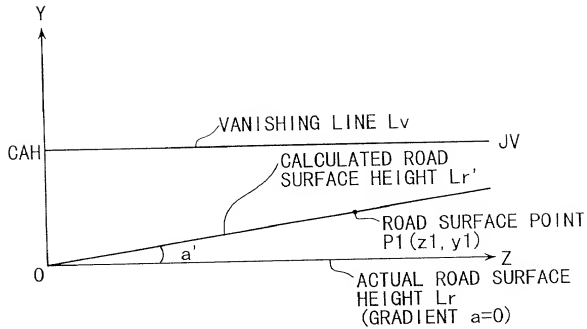


FIG. 9

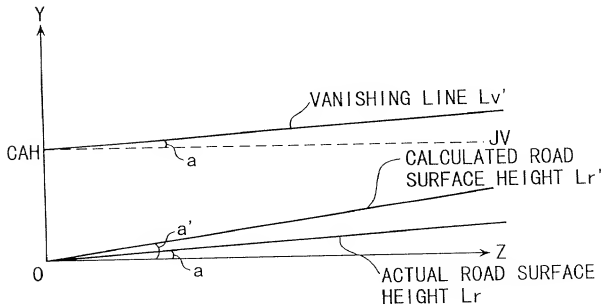


FIG. 10

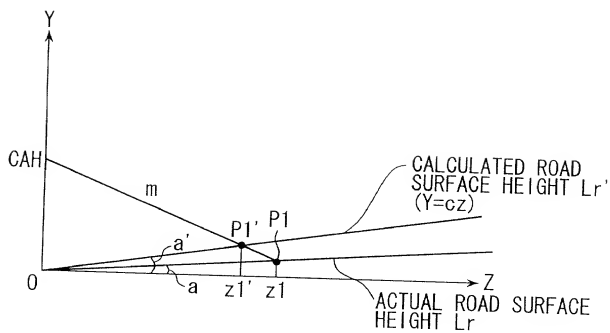


FIG. 11

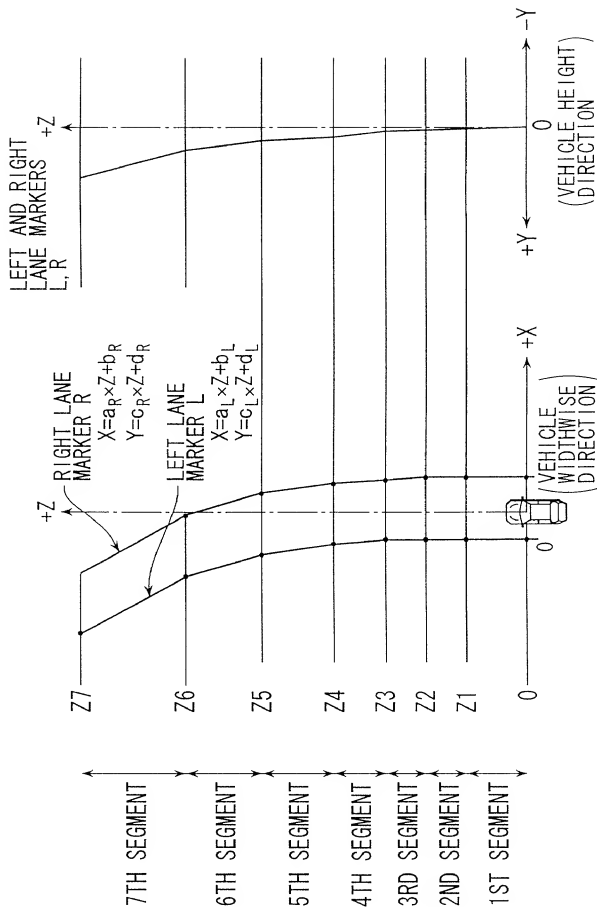


FIG. 12

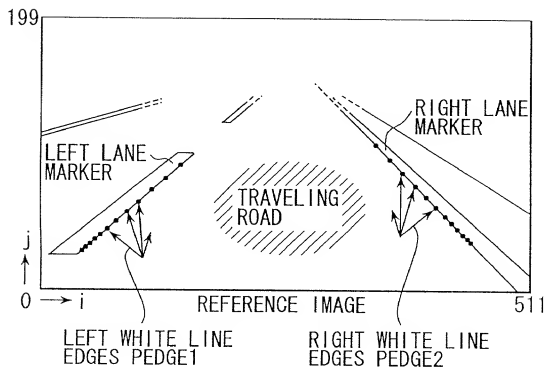


FIG. 13

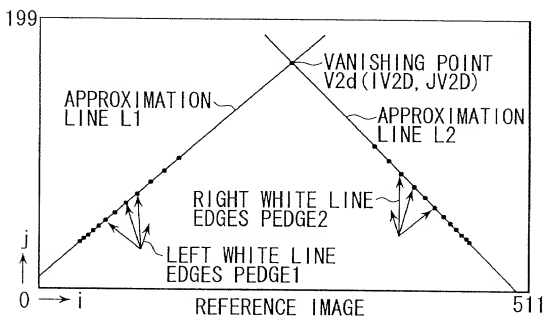


FIG. 14

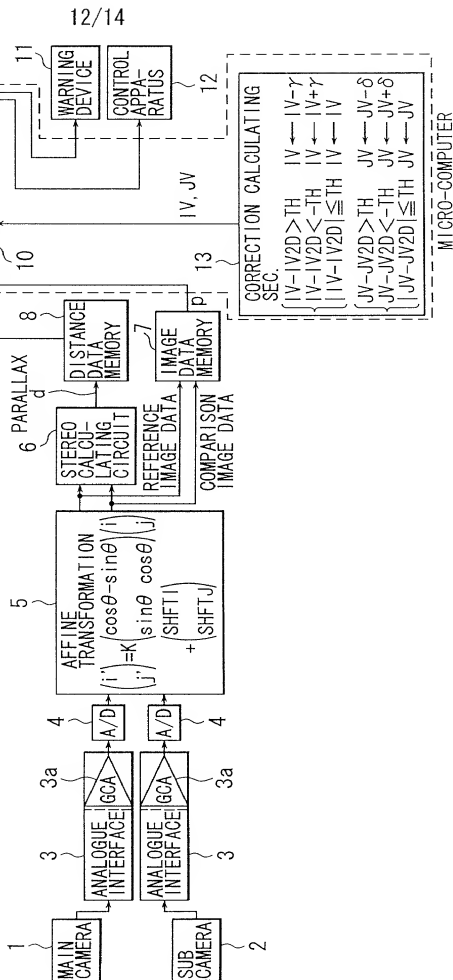


FIG. 15

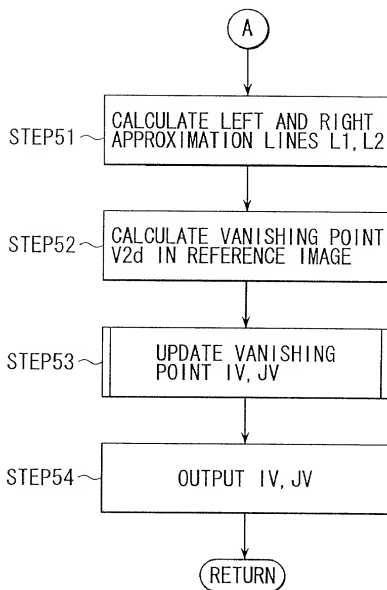


FIG. 16

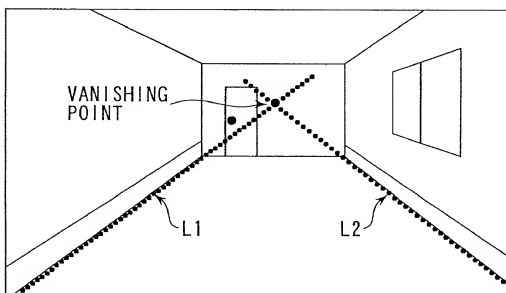
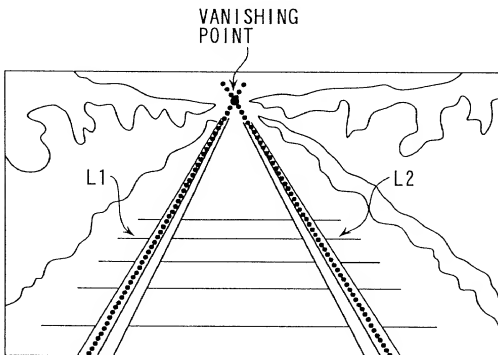


FIG. 17



Declaration and Power of Attorney United States Patent Application

UNITED STATES
Patents and Design Patents
Sole & Joint Inventors
Convention & Non-convention
PCT & Non-PCT

This form cannot be amended, altered
or changed after it is signed
(For use only for inventors who
understand the English language)

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

DISTANCE CORRECTING APPARATUS OF SURROUNDINGS MONITORING SYSTEM AND VANISHING POINT CORRECTING APPARATUS THEREOF

(check one) ☒ is attached hereto.

☐ was filed as U.S. Application No. _____ on _____ and (if applicable) was amended on _____.

☐ was filed as PCT International Application No. _____ on _____ and (if applicable) was amended under PCT Article 34 on _____.

(I authorize any attorney appointed below to insert information in the preceding blanks.)

I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) or §365(b) of any foreign and PCT application(s) for patent or inventor's certificate, or §365(a) of any PCT international application which designated at least one country other than the United States of America listed in this Declaration. I have also identified below any foreign application for patent or inventor's certificate or PCT international application having a filing date before that of the application(s) on which priority is claimed:

Foreign/PCT Application No.	Country	Filing Date	Priority Claimed? (yes/no)
11-268015	JAPAN	22 SEPTEMBER 1999	YES

I hereby claim the benefit under Title 35, United States Code, §120 or §365(c) of any United States application and PCT international application designating the United States of America listed in this Declaration and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application or PCT international application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

U.S. Application No.	Filing Date	Status (patented/pending/abandoned?)

I hereby claim priority benefits under Title 35 United States Code §119(e) of any U.S. provisional application(s) listed below:

U.S. Provisional Application No.	Filing Date

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: Robert G. Weilacher (20,531), Herbert M. Hanegan (25,682), Frederick F. Calvetti (28,557), J. Rodgers Lunsford, III (29,405), Michael A. Makuch (32,263), Dennis C. Rodgers (32,936), William F. Rauchholz (34,701), Michael C. Carrier (42,391), Eric J. Hanson (44,738), Patrick R. Delaney (45,338), Donna D. King (45,962), Joseph M. Lewinski (46,383) and Brandon S. Boss (46,567).

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Date: _____

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Signature: _____
☐ Additional inventors and/or prior applications are listed in attached Supplemental Sheet(s).

Date: _____

SGR/BDWY